Dynamical Solutions to the Ground State of a Frustrated Magnet

PHYS 598 Introduction Presentation

Scott Salmon
Faculty of Science – Department of Physics and Astronomy
Supervisor: Dr. David L. Feder

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What is a Magnet?

- A magnet is a material where the atomic dipoles exhibit some kind of spatial order. Depending on the alignment of the dipoles, a magnetic field may be produced.

- This field is what produces a force that attracts or repulses other ferromagnetic materials, such as iron, nickel, cobalt, etc.

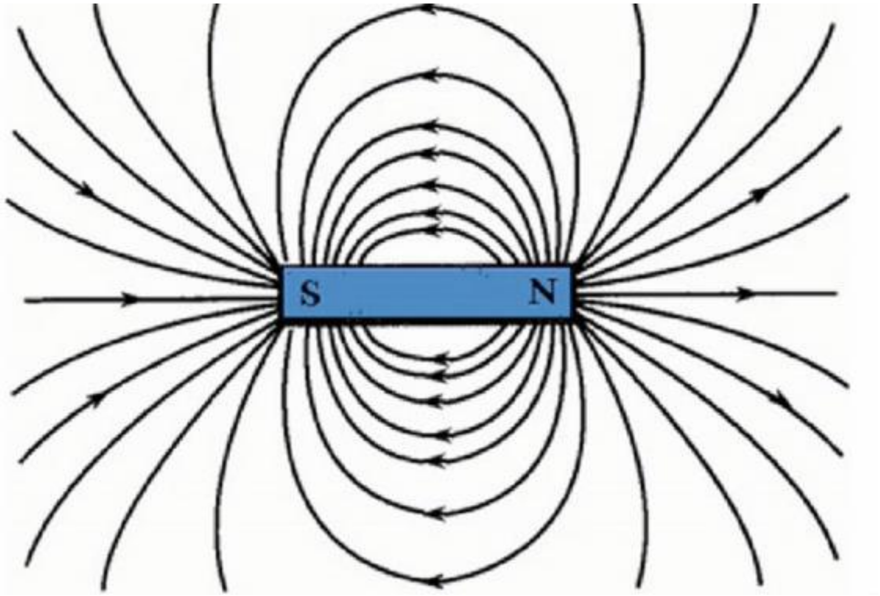
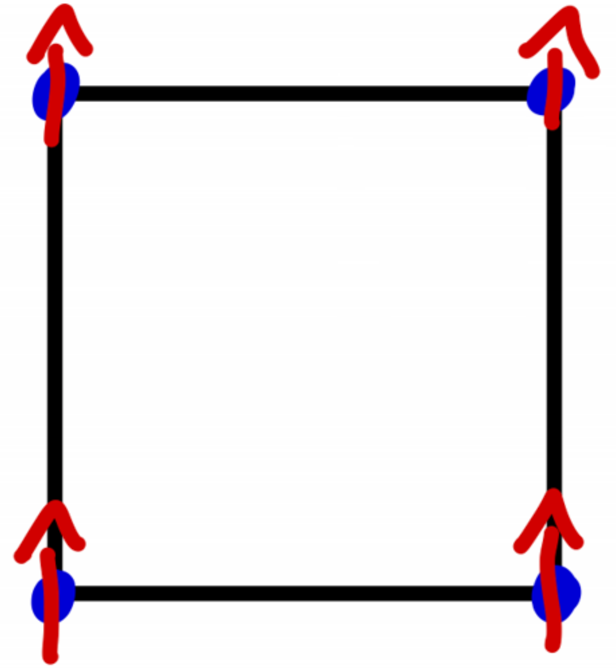


Figure 1: Magnetic field lines of a dipole [1]

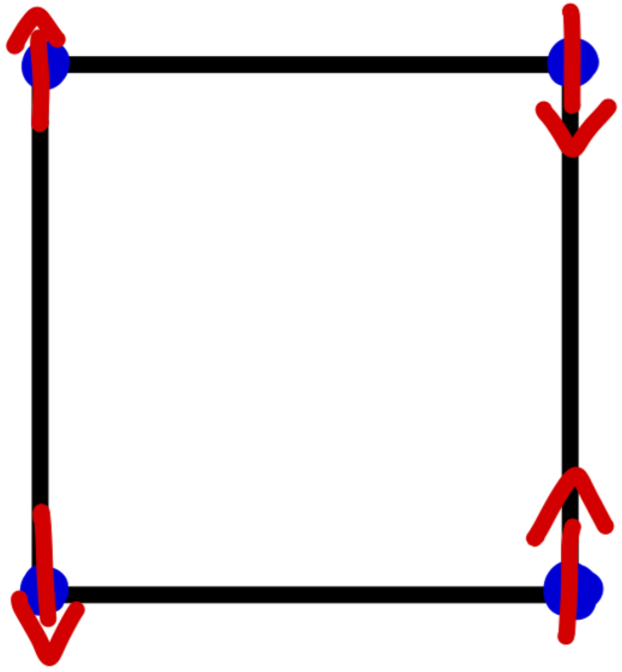
[1] Lokesh Sharma, "*Enhancing QoS for Multimedia Services Using Mobility-Aware Bandwidth Estimation Algorithm in MANETs*" (2017) https://www.researchgate.net/figure/Magnetic-field-lines-of-a-dipole-10_fig7_322069152

Three types of Magnet Dipole Alignment



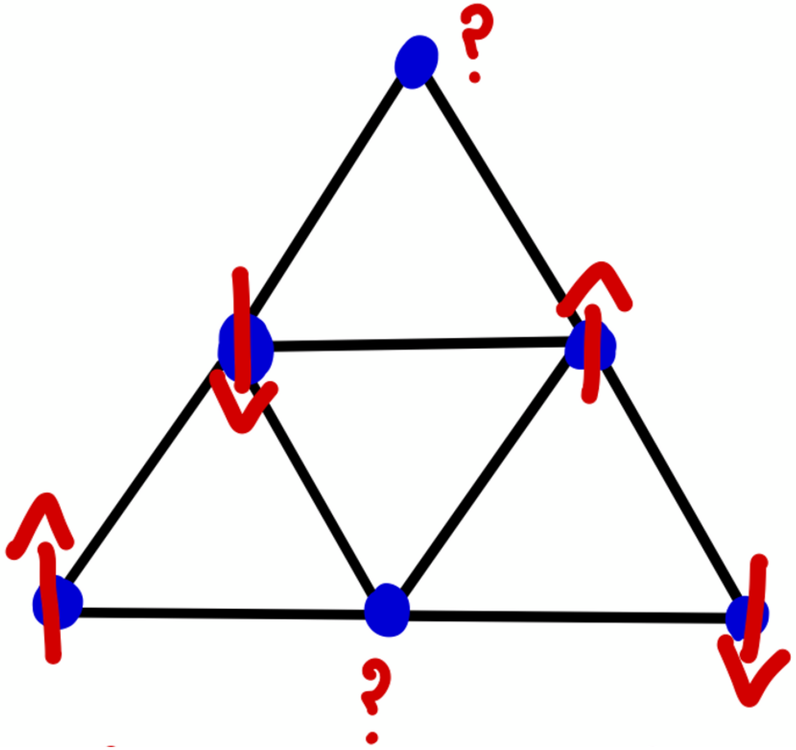
Ferromagnetic

Dipoles aligned in a regular pattern in same direction



Anti-Ferromagnetic

Dipoles aligned in a regular pattern in opposite direction



Frustrated Ferromagnetic

Dipoles are not aligned in a regular pattern

GP Equation and BECs

- A Bose-Einstein Condensate (BEC) is modeled accurately by an equation known as the Gross-Pitaevskii (GP) equation. A time-dependent form of this equation is shown below.

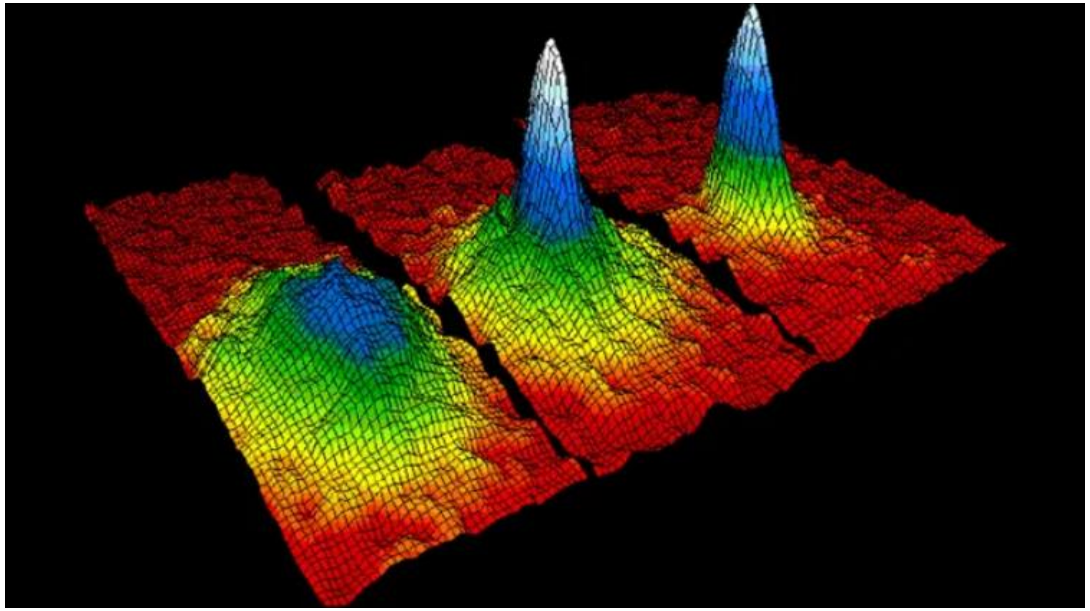


Figure 2: Series of images show from left to right the increasing density of rubidium atoms beginning to form a Bose-Einstein Condensate [2]

$$i\hbar \frac{\partial \Psi(\mathbf{r},t)}{\partial t} = \left(-\frac{\hbar^2}{2m}\nabla^2 + V(\mathbf{r}) + g|\Psi(\mathbf{r},t)|^2 \right) \Psi(\mathbf{r},t).$$

[2] NIST/JILA/CU-Boulder "*Grapic: 3-D of Atom Condensing*" (2006) https://www.nist.gov/image/quantumphysicsboseeinsteincondensatejpg

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Different Problem, Similar Approach

- The GP Equation used non-linearity to reach an approximation of the ground state of the BEC system. What if we added non-linearity to another complex system? Could it produce similar results?

- In this case, what if we analyzed a frustrated magnet system and see if adding non-linearity could be used to find an approximation of its ground state?
  - Instead of treating the whole system as a single-particle like how the GP equation analyzes a BEC, we would instead only add non-linearity at the boundaries.

Objective: Simulation with a Classical Computer

- The primary objective of this project will be the creation of a simulation using a classical computer to put this theory to the test.
- I would simulate the time propagation of the system with a small number of quantum particles, which will take a combination of computing, linear algebra and differential equation skills to complete.

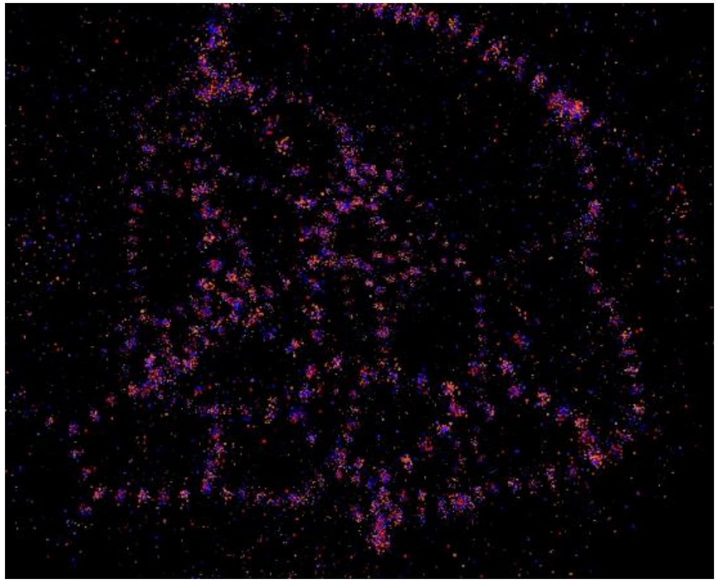

Figure 3: Simulation of Emergent Structures/Molecules [3]

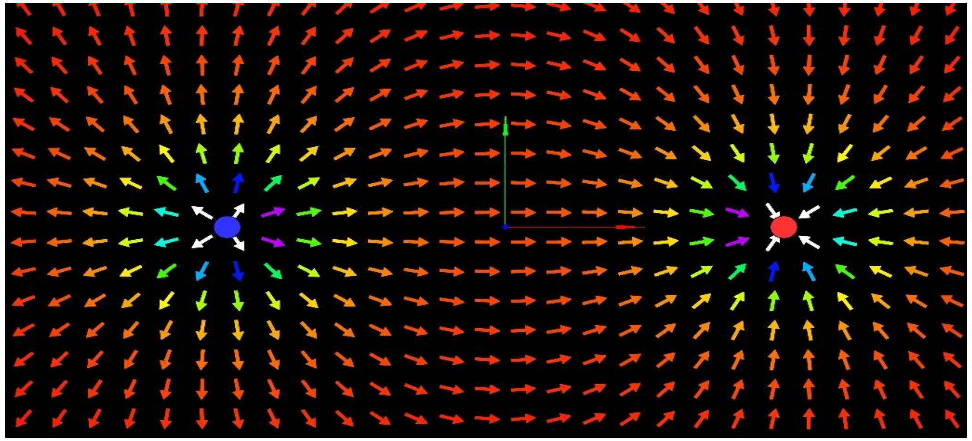

Figure 4: Simulation of an Electromagnetic Field [3]

[3] andrelsn *"Particle Physics Simulation"* [Online forum post]. Reddit. (2022). https://www.reddit.com/r/Physics/comments/zcmqui/particle_physics_simulation/

Future Application: Simulation with a Quantum Computer

- If the idea looks promising, then my work could be continued and eventually mapped to a quantum computer.
- This is significant, because quantum computers do not have the same limitations that classical computers do, which means much larger simulations may be able to be created.

Figure 5: Photograph of Google's Quantum Computer [4]

[4] Google Quantum AI *"Quantum Computer"* https://quantumai.google/quantumcomputer

Literature Survey

- Giuseppe Grosso & Giuseppe Pastori Parravicini. (2000) *Solid State Physics.* Academic Press. https://doi.org/10.1016/B978-0-12-304460-0.X5000-2

- Billington, D., Ernsting, D., Millichamp, T. et al. (2015) *Magnetic frustration, short-correlations and the role of the paramagnetic Fermi surface of $PdCrO_2$.* Scientific Reports. https://doi.org/10.1038/srep12428

- Kenichi Kasamastu, & Makoto Tsubota. (2009) *Progress in Low Temperature Physics: Quantum Turbulence.* Elsevier. https://doi.org/10.1016/S0079-6417(08)00007-3

Thank you for your time!

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